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# High Spectrum Narrowing Tolerant 112 Gb/s Dual Polarization QPSK Optical Communication Systems using Digital Adaptive Channel Estimation

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**Abstract:** We experimentally demonstrate high spectrum narrowing tolerant 112-Gb/s QPSK polarization multiplex system based on digital adaptive channel estimation method. The proposed algorithm is able to detect severe spectrum-narrowed signal even with 20GHz 3dB bandwidth.

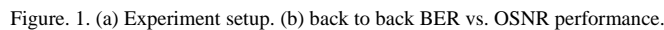
**OCIS codes:** (060.1660 Coherent communications)

## 1. Introduction

With the rapid growth of capacity requirements of optical transmission networks, there is a strong need to realize high capacity and high spectral efficient (SE) optical communication systems. The ultra-dense wavelength diversity multiplexing (U-DWDM) technology based on advanced modulation format is a promising solution and is being intensively studied [1,2]. U-DWDM technology requires optical or electrical pre-filtering to fulfil Nyquist sampling criterion [3]. Meanwhile, to facilitate ease of optical networking, tolerance of spectrum narrowing is critical, as signal channel spacing is degraded after transmission through optical channel, especially when reconfigurable optical add/drop multiplexers (ROADMs) nodes are used in the network [4]. Spectrum narrowing severely induce inter symbol interference (ISI) between continual transmitted sequence. Therefore, ISI compensation is essential to improve U-DWDM system performance in terms of optical signal to noise ratio (OSNR). Conventional digital signal processing (DSP) algorithm using adaptive decision feed forward equalizer is an inefficient solution, since this finite impulse response (FIR) filter enhance noise during compensation of spectrum narrowing [5]. Although maximum-likelihood sequence estimation (MLSE) method has been successfully proved to mitigate ISI [6], the complexity of MLSE is exponentially increasing with the length of transmitted sequence. When the sequence length is large, optimal MLSE becomes unfeasible. Therefore, in order to achieve high spectrum narrowing tolerant optical communication system, we implement adaptive channel estimation DSP algorithms combined with decision feedback equalizer. As a result, we experimentally demonstrate the high spectrum narrowing tolerance of proposed algorithms for 112 Gb/s dual polarization (DP) quadrature phase shift keying (QPSK) transmission systems.

## 2. Experiment Setup

Figure 1(a) shows the experiment setup of 112 Gb/s DP QPSK optical communication system. A DFB laser operating at 1549.53 nm (193.47 THz) with 10 MHz line-width is used as optical signal source to generate the QPSK signal. The pulse pattern generator (PPG) working at 28 Gbaud/s is operated as electrical signal source with  $2^{15}-1$  bit length to drive the optical QPSK modulator. After the QPSK modulator, optical channel is separated into two orthogonal polarizations by a polarization beam splitter (PBS). Afterward, two branches of orthogonally polarized optical channels are combined by a polarization beam combiner (PBC) to generate the 112 Gb/s DP QPSK signal. The Finisar<sup>®</sup> wave-shaper is then used as spectrum pre-filtering optical bandpass filter (OBPF). The OBPF is able to tune full width at half maximum (FWHM) of transmitted signal. FWHM is defined as 3dB bandwidth of transmitted signal. At the receiver side, a pre-amplified coherent receiver structure is implemented. A tunable optical band-pass filter (with 0.5 nm/ 62.5 GHz FWHM) is used after the pre-amplifier in order to remove ASE noise from the EDFA. The local oscillator (LO) is a wavelength tunable external cavity laser (ECL) with 100 kHz line-width. In the coherent receiver structure, tuning LO wavelength enables channel selection due to optical heterodyning at the photodiode. The coherent receiver consists of two 90° hybrids and balanced detectors. The 80 Gb/s digital sampling oscilloscope at the coherent receiver is used to sample the inphase and quadrature components. Figure 1(b) shows the back to back transmission bit error rate (BER) performance in terms of OSNR. In both results of simulation and experiment for back to back transmission, at 20 dB OSNR measurement point, BER performances are approaching zero, and at 16 dB OSNR measurement point, BER performances are around  $10^{-3}$ . In the experiment, we focused on these two OSNR measurement points (OSNR=16dB and OSNR=20dB) and use DSP algorithm to compensate ISI induced by spectrum narrowing effect. We also employed constant modulus algorithm (CMA) to enable polarization rotation compensation, frequency and phase offset removal, QPSK demodulation and bit error detection.



The proposed DSP algorithm schematic is shown in Figure 2. The polarization multiplexed signals are firstly fed into coherent detection receiver. Afterward, the received signals are sampled by analog to digital convertor (ADC) to 2 samples per symbol. The output digitized signals are fed into a butterfly filter composed of four FIR filters. CMA algorithm is used to improve polarization demultiplex performance and compensate polarization rotation. The signals are sent to carrier recovery block to demultiplex inphase and quadrature components and then to the adaptive channel estimation block. The adaptive channel estimation requires estimation of noise level  $\eta_k$ ; feed forward FIR tap coefficients  $c_k$  and feed back equalizer tap coefficients  $p_k$ . For instance, in one orthogonal polarization, denoted as x-polarization, input of channel estimation is  $x(k)$ . Since a finite length feed forward equalizer is unable to cancel noncausal ISI completely, the feed back filter coefficients should be optimized according to the MMSE criterion whereby the additive noise power resulting from residual ISI is minimized. The correct channel estimation of  $c_k$  and  $p_k$  is able to minimize minimum mean square error (MMSE) between received signals and decision signals [7], i.e.  $\min\{E[x'(k) - \eta - \tilde{x}''(k)]^2\}$ , where  $x'(k) = c_k x(k)$  and  $\tilde{x}''(k) = x'(k) - p_k \tilde{x}'(k)$  and  $\tilde{x}'(k)$  is the slicer output from  $x'(k)$ . The stochastic adaptive algorithm to find  $c_k$ ,  $\eta_k$  and  $p_k$  can be implemented using the LMS algorithm [8].

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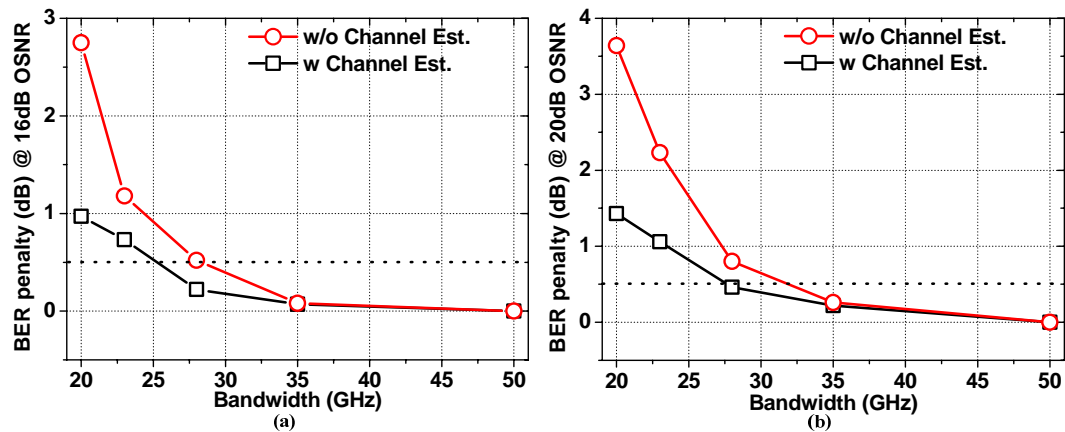


Figure. 3 BER penalty vs. bandwidth narrowing with and without adaptive channel estimation algorithm. (a) @ 16dB OSNR. (b) @ 20dB OSNR

Figure 3 shows experiment results. In our experiment, we focus on 20 dB OSNR and 16 dB OSNR measurement points. At 20 dB OSNR, in case of without spectrum narrowing effect, BER performance is error free. As the signal spectrum space degrading, BER penalty grow dramatically. Meanwhile, using adaptive channel estimation algorithm, strongly reduce the BER penalty. Especially at 20 GHz bandwidth (71% of original signal bandwidth), BER penalty is reduced 2 dB by using adaptive channel estimation algorithms. At 20 dB OSNR, in case of with out spectrum narrowing effect, BER performance is around  $10^{-3}$ . At 20 GHz bandwidth (71% of original signal bandwidth), BER penalty is also reduced 2 dB by using adaptive channel estimation algorithms.

#### 4. Conclusion

By using our proposed adaptive channel estimation DSP algorithms, we successfully demonstrate high spectrum narrowing tolerant 112-Gb/s QPSK polarization multiplex optical communication systems. The experiment results show that in case of 71% spectrum narrowing, our proposed algorithms mitigate 2 dB BER penalties with both 16 dB OSNR and 20 dB OSNR cases. Compared to high computational complexity requirement of MLSE algorithm, our proposed adaptive channel estimation DSP algorithm is feasible and practical.

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